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PECULIARITIES OF DISPERSION OF PROTON WHISTLERS DETECTED ON AES "INJUN-3" AND "ALOUETTE-1"

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SUMMARY

The author discusses several of the recent U.S. works on proton whistlers, and develops a few considerations leading to the explanation of certain peculiarities of proton whistler dispersion.

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An interesting phenomenon was revealed on board AES Injun-1 and Alouette-1 namely proton whistlers [1 – 5]. These are electromagnetic signals in the ~ 0.5 kc band, of which the instantaneous frequency Ω accrues with time, approaching asymptotically the proton gyrofrequency Ω at the place of location of the device. The duration of the signal is ~ 2 sec.

Proton whistlers may be utilized for the determination of ion concentration and magnetic field intensity in the plasma surrounding the satellite [5]. The possibility of the diagnosis arises owing to the fact that as $\omega \rightarrow \Omega$ the character of dispersion of ion-cyclotron waves is quite sensitive to plasma parameter variation. But in this frequency range the dispersion is essentially dependent also on the motion velocity of the plasma relative to the observer. Apparently, the dispersion of proton whistlers, which is the object of the present note, may be explained by the above considerations.

In a quiescent plasma the index of refraction of ion-cyclotron waves is determined by the expression

$$\frac{n^2}{n_a^2} = \frac{\Omega}{\Omega - \omega} \frac{1 + \cos^2 \alpha}{2 \cos^2 \alpha}, \tag{1}$$

where $n_a^2 = c^2 / v_a^2$, v_a is the Alfven velocity, ω is the angle between $\vec{k}$ and $\vec{H}$. When $\alpha = 0$ and as $\Delta \rightarrow 0$ the time of group signal lag depends on wave frequency as follows [5]: $\tau \sim \mathrm{const}\, \Delta^{-1/2}$, where $\Delta \equiv (\Omega - \omega) / \Omega$, and the proportionality factor is the proton conservation function N(H+) in the neighborhood of the satellite.

(*) OSOBENNOST' DISPERSII PROTONNYKH SVISTOV OBNARUZHENNYKH NA SPUTNIKAKH "INJUN-3" i "ALUETT-1".

The experiment provides the dependence $\tau(\omega)$ directly. For the determination of Ω (and then also N(H+)) graphs of $\tau=\tau(\Delta^*)$ were constructed in [5] for several test values Ω^*, whereupon considered as real was the test value of Ω that provided a linear dependence of τ on $\Delta^{-1/2}$. Consideration of Fig.10 of ref.[5] shows, however, that the scattering of the points in case of linear dependence ($\Omega^* \approx 528$) is greater than in the case when the dependence $\tau(\Delta^{-1/2})$ is clearly nonlinear ($\Omega^* \approx 532$). The value $\Omega \approx 532$ is more realistic, for it gives a smaller quadratic deflection. Judging from Fig.11 of [5], the estimate of N(H+) must then be increased $\sim$1.5 times.

The departure of the dependence $\tau(\Delta^{-1/2})$ from linearity is explained by plasma motion along the lines of force of the geomagnetic field relative to radiation receiver. The correction for the index of refraction, conditioned by plasma motion with velocity u is [6]

$$\frac{\delta n}{n} \approx -\left(\frac{u}{v_a}\right)\left(\frac{\Omega}{\Omega-\omega}\right)^{3/2} \frac{(1+\cos^2\alpha)^{1/2}}{2\sqrt{2}\cos\alpha}. \tag{2}$$

Hence it is not difficult to obtain the asymptote of signal's group time lag at $\alpha = 0$ and as $\Delta \to 0$

$$\tau \sim \frac{\text{const}}{\sqrt{\Delta}}\left\{1-\frac{u/v_a}{2\Delta^{3/2}}\right\}. \tag{3}$$

Because of Landau attenuation the quantity Δ is bounded from below:

$$\Delta_{\min} \sim (v_T / v_a)^{2/3},$$

where $v_T = \sqrt{2T/m_i}$ is the thermal velocity of protons [7]. Therefore, the maximum correction $\delta\tau$ to group time lag will be of the order $|\delta\tau/\tau|_{\max} \sim u/2v_T$. For $u \sim 3 \cdot 10^5$ cm/sec and $v_T \sim 5 \cdot 10^5$ cm/sec, $|\delta\tau/\tau|_{\max} \sim 0{,}3$, will be quite a noticeable quantity.

The velocity u is composed of satellite velocity projection on signal trajectory and plasma longitudinal drift velocity. It is apparently premature to speak in terms of the possibility of determination of plasma longitudinal drift velocity by the dispersion of proton whistlers in the region of small Δ. The experimental and theoretical investigation of this question would be quite desirable. Note that the concomitant on board measurements of the magnetic field would have allowed us to completely eliminate the uncertainty in Ω and to increase, by the same token, the precision of determination of dispersion curve's $\tau(\Delta)$ parameters.

In a drifting plasma there arises not only a complementary signal lag (positive or negative depending upon the sign of $\vec{k}\cdot\vec{u}$), but also the distortion of its trajectory. Let us show that in this case this effect can be neglected. The value of the correction $\delta\psi$ to the angle ψ between $\vec{k}$ and $\partial\omega/\partial\vec{k}$ is, with a precision to the multiplier [6]

$$\delta\psi \sim \left(\frac{u}{v_a}\right)\left(\frac{\Omega}{\Omega-\omega}\right)^{3/2} \frac{\sin\alpha}{2\sqrt{2}}. \tag{4}$$

As is well known [7], in the region of electromagnetic ion-cyclotron resonance the propagation is quasi-longitudinal ($\sin\alpha \ll 1$) ; the product of comultipliers in parentheses of (4) is knowingly less than the unity, and this means that $\delta\psi \ll 1$.

*** THE END ***

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